International Journal of Robotics and Automation (IJRA)
Vol. 7, No. 3, September 2018, pp. 169~175
ISSN: 2089-4856, DOI: 10.11591/ijra.v7i3.pp169~175

Green Two-wheeled Mobility: Electric Scooters using Brushless Motor based on Fuzzy Logic Controller

Hassane Bachiri, Abdelfetah Nasseri
Department of Electrical Engineering, Bechar University, Algeria

Article Info

Article history:

Received Feb 6, 2018
Revised Jun 19, 2018
Accepted Jul 5, 2018

Keyword:

BLDC motor
Fuzzy logic controller
PID controller
Scooter

ABSTRACT

In the last years electric vehicles gained importance as a more sustainable alternative to traditional vehicles. The introduction of an electric power train leads to lower air-pollution emissions. 'Electric bicycles' are sometimes more like an electric pedaled moped, other times more like a Vespa-looking scooter with or without pedals, and they often offer good range and speeds. However, a "scooter" can also be an electric cart for personal mobility, or a skateboard-like vehicle with small handlebars. Electric scooters are the most legislatively active realm of electric bicycles, at the present time. Brushless DC (BLDC) motors are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance. In this paper, the modeling and simulation of the BLDC motor was done using the software package Matlab/Simulink. The proposed fuzzy logic controller has given optimal results compared to PI controller. The simulated system using the fuzzy controller has a fast response without overshoot, zero steady state error and high load robustness.

Corresponding Author:
Hassane Bachiri,
Department of Electrical Engineering,
Bechar University,
BP 417, Bechar, Algeria.
Email: bachiri_hassane@aol.fr

1. INTRODUCTION

Air pollution is a major problem in our current society, PM, NO2, O3 and CO cause health problems while CO2 emissions have environmental impacts [1]. One of the largest emitters is the transport sector. To reduce pollution by passenger transport, the European Union (EU) has mapped a strategy to increase electric-based transport. In the EU the emissions from the extra electricity generation that is needed for electric transport are lower that the emissions for the currently used fossil fueled transport options. Studies show that electric cars are too expensive to compete with internal combustion engine (ICE) vehicles. Electrification via electric two-wheeler (ETW) technology could be an option, especially in urban regions [2]. In the next section, we will study an electric scooter that has a brushless DC motor (BLDC). The control of BLDC has been done by a conventional PI controller at the first time. The performances of this PI controller need to be improved due to the overshoot and settling time of the speed response. To achieve this goal, we have proposed a Fuzzy logic Controller which has improved substantively all the characteristics of the BLDC due to the adequate choose of the fuzzy inference properties and also the number of the membership functions and their values. The obtained results shown later confirm these choose.

2. STUDY OF SCOOTER

The Scooters has been made from 1914 or earlier. They became more popular from the post-World War II with the introduction of the *Vespa* and the *Lambretta*. These scooters were intended to provide economical personal transportation (engines from 50 to 250 cc). Maxi-scooters, with engines from 250 to 850

cc have been developed for Western markets. Scooters are popular for personal transport, partly due to being more affordable, easy to operate and convenient to park and store. This future green urban transport has been defined by the Oxford dictionary as follows: ‘A light two-wheeled open motor vehicle on which the driver sits over an enclosed engine with their legs together and their feet resting on a floorboard [3]. The European Commission (EC) classifies two-wheelers based on their maximum power and speed (Table 1). One exception is made here for bicycles. EC is not applicable to vehicles with pedal assistance with a maximum power of 0.25 kW and a maximum speed of 25 km/h. We use this description to categorize bicycles and electric bicycles, with the difference that bicycles are 100% human propelled and electric bicycles have an assisting electric motor [4].

Table 1. Categorization of Two Wheelers Based on European Commission

Category	Speed (km/h)	Internal Combustion Engine size (cm3)	Electric Engine Power (kW)	Specifics
Mopeds/Scooters	0 - 45	0 – 50	0 – 4	-
Motorcycles	>45	>50	-	-

Some other characteristics have been cited in the literature [5]-[9] as is shown in the Table 2.

Table 2. Vehicle Characteristics

Characteristics	Electric scooter
Capacity (kg) (Including rider 70 kg)	180-250
Recharge time (h)	3-5
Average speed (km/h)	35
Autonomy (km)	30-120
Driving (adverse conditions)	Easy

The simulated scooter based on FLC uses a permanent magnet brushless which has been developed since the late 1980’s. It can be classified upon to the back-EMF waveform, where it can be operated in either brushless AC (BLAC) or brushless modes. Usually the BLAC motors have a sinusoidal back-EMF waveform and BLDC motors have a trapezoidal back-EMF. BLDC motors are used in industries such as Appliances, HVAC industry, medical, electric traction, road vehicles, aircrafts, military equipment, hard disk drive, etc. Comparing BLDC motors with DC motors, the DC motor have high starting torque capability, smooth speed control and the ability to control their torque and flux easily and independently.

In the DC motor, the power losses occur mainly in the rotor which limits the heat transfer and consequently the armature winding current density, while in BLDC motor the power losses are practically all in the stator where heat can be easily transferred through the frame, or cooling systems can be used specially in large machines. In general the induction motor has many advantages as: their simplest construction, simple maintenance, low price and reliability. Furthermore, the disadvantages of induction machines make the BLDC motors more efficient to use and become more attractive option than induction motors [10]-[12].

In electric scooters industry productions the brushless direct current motors are rapidly gaining popularity. The drive of an electric scooter basically consists of a motor and transmission, the driving motor is BLDC type, and the mechanical transmission structure is either a chain with gearbox or a continuously variable transmission. Most electric motorcycles and scooters today are powered by rechargeable batteries. In 2017, the first vehicle in the US to use the new Lithium Titanium Oxide (LTO) battery non-flammable battery technology [13] is a scooter called *The Expresso.*

3. MODELING OF THE BLDC MOTOR

It is assumed that the BLDC motor is connected to the output of the inverter, while the inverter input terminals are connected to the output of the controller PI/Fuzzy, as shown in Figure 1. Another assumption is that there are no power losses in the inverter and the 3-phase motor winding is connected in star.

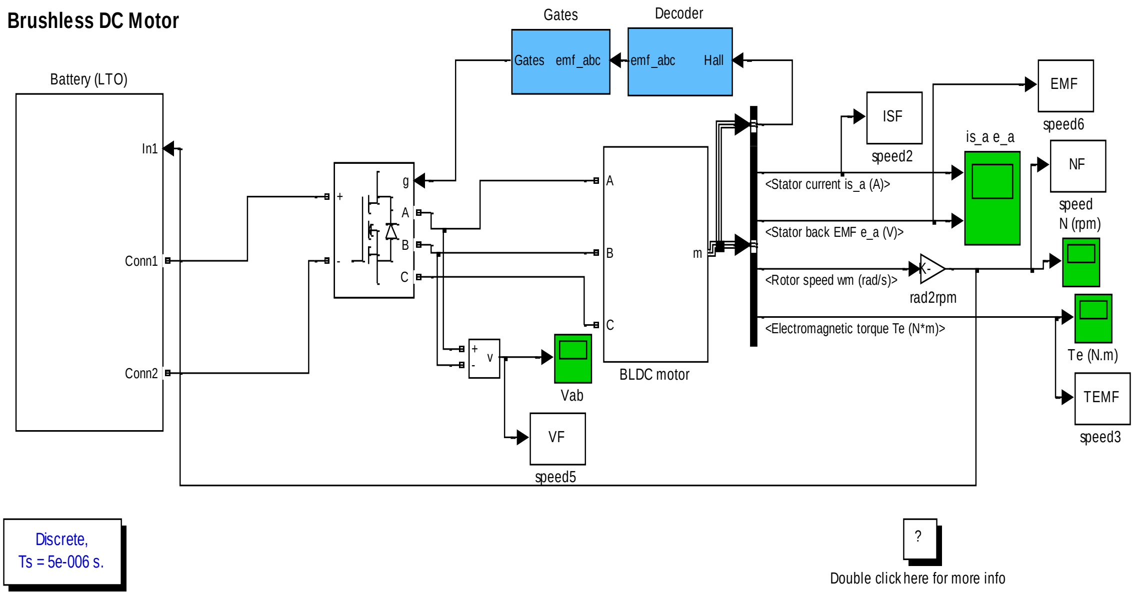

Figure 1. Simulation scheme of the scooter BLDC motor

For a symmetrical winding and balanced system, the voltage equation across the motor winding is as follows. Applying Kirchhoff's voltage law for the three phase stator loop winding circuits yields (1):

$$\begin{aligned} V_a(t) &= R_a i_a + L_a \frac{di_a}{dt} + M_{ab}\frac{di_b}{dt} + M_{ac}\frac{di_c}{dt} + e_a \\ V_b(t) &= R_b i_b + L_b \frac{di_b}{dt} + M_{ba}\frac{di_a}{dt} + M_{bc}\frac{di_c}{dt} + e_b \\ V_c(t) &= R_c i_c + L_c \frac{di_c}{dt} + M_{ca}\frac{di_a}{dt} + M_{cb}\frac{di_b}{dt} + e_c \end{aligned} \tag{1}$$

where the back-EMF waveforms ea, eb and ec are functions of angular velocity of the rotor shaft, so (2):

$$e = k_c \omega_m \tag{2}$$

where k_c is the back-emf constant. The electromechanical torque is expressed as shown in (3) [14]-[15]:

$$T_{em} = J\frac{d\omega_r}{dt} + B\omega_r + T_L \tag{3}$$

4. FUZZY LOGIC CONTROLLER

The structure of the proposed controller for BLDC motor is shown in Figure 2. The proposed controller consists of fuzzy logic controller which supplies the DC bus. The designation of fuzzy logic controller is based on expert knowledge which means the knowledge of skillful operator during the handling of BLDC motor system is adopted into the rule based design of fuzzy logic controller. The inputs of the fuzzy logic controller (FLC) are the error and the change of error. The Figures 3, 4 and 5 show the membership functions of the inputs and output of the FLC and in Figure 6 is the FLC's parameters according to the FIS properties.

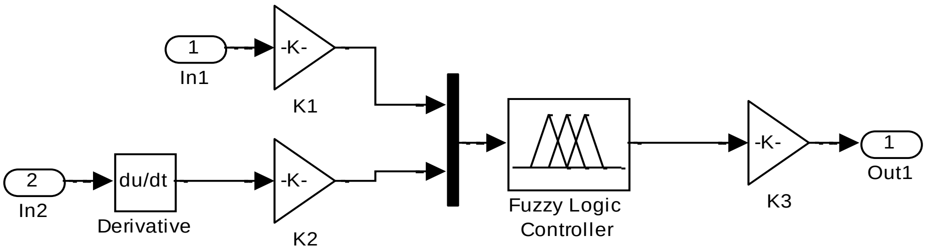

Figure 2. Proposer fuzzy controller

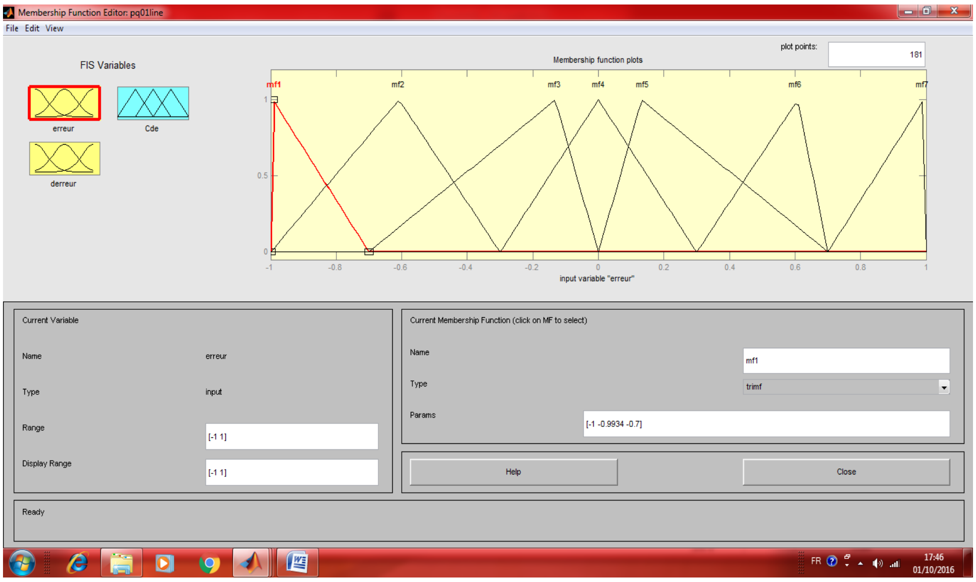

Figure 3. Membership functions of the input ‘error’

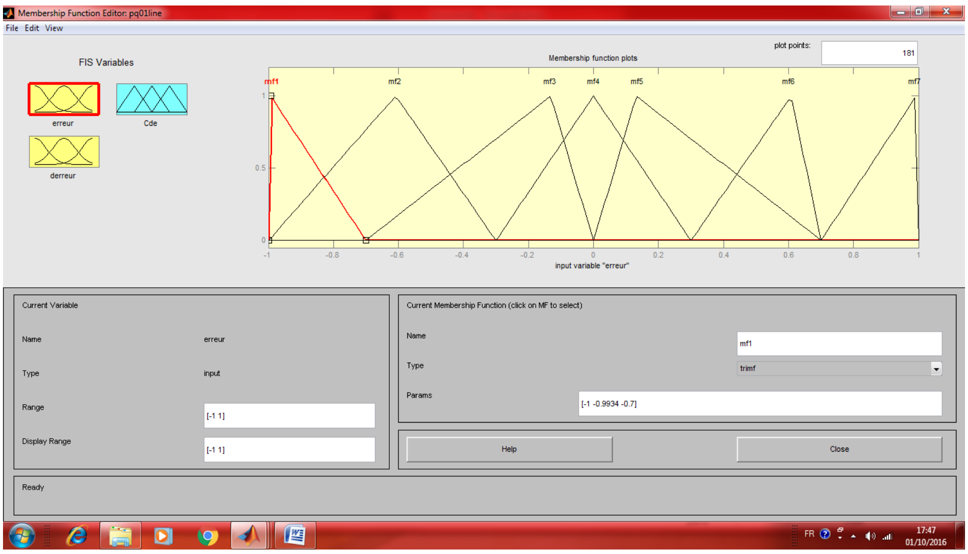

Figure 4. Membership functions of the input ‘change of error’

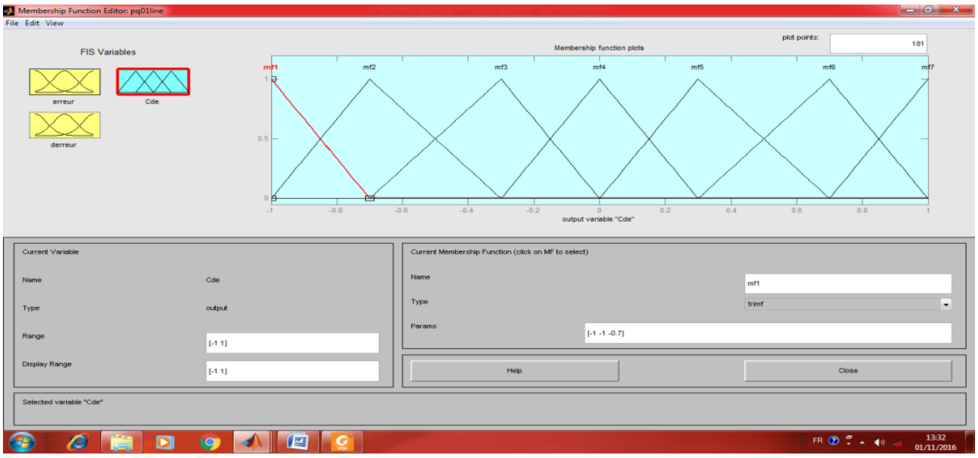

Figure 5. Membership functions of the output ‘control’

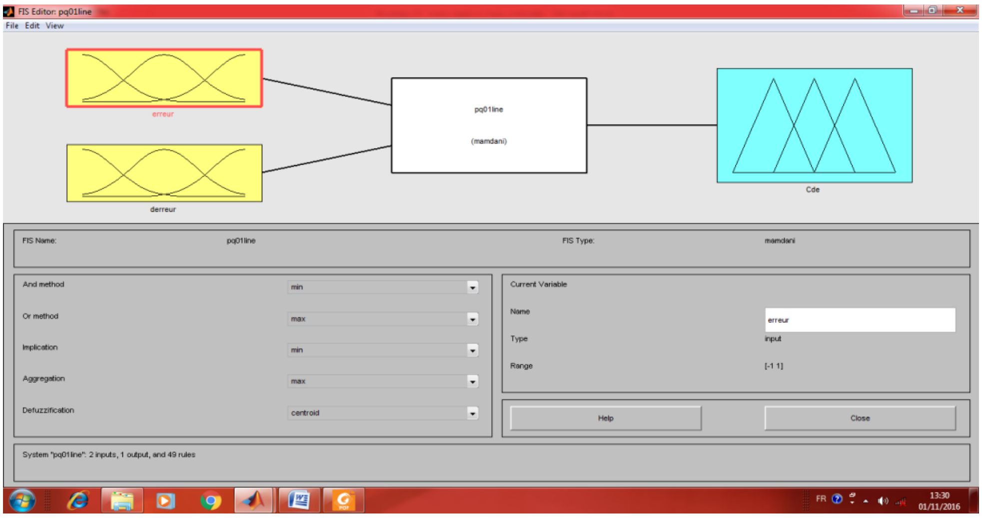

Figure 6. Fuzzy Inference System properties of the proposed FLC

In Table 3 fuzzy inference system properties of the proposed FLC. The parameters on Figure 6 show the configuration of the proposed FLC. We have used the max-min inference method, an OR operator for the aggregation and the centroid method for the defuzzification as shown in (4):

$$z^{*} = \frac{\int \mu(z) z dz}{\int \mu(z)} \tag{4}$$

Table 3. Fuzzy Inference System Properties of the Proposed FLC

And method	min
Or method	max
Implication	min
Aggregation	max
Defuzzification	centroid

5. SIMULATION AND RESULTS ANALYSIS

A simulation of a brushless DC motor system with the PI and FLC using the above equations was performed using MATLAB. Speed response of the PI controller as shown in Figure 7. Speed response of the FLC as shown in Figure 8 and in Figure 9 comparison of speed responses of both PI and FLC.

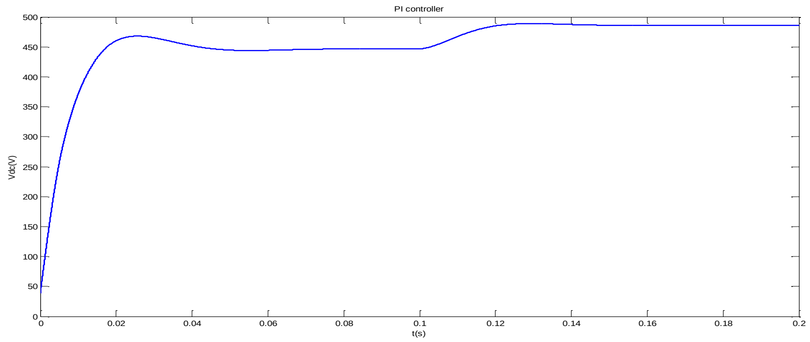

Figure 7. Speed response of the PI controller

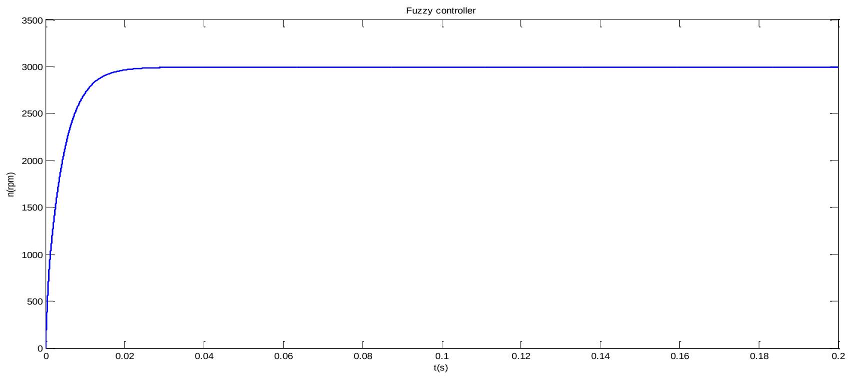

Figure 8. Speed response of the FLC

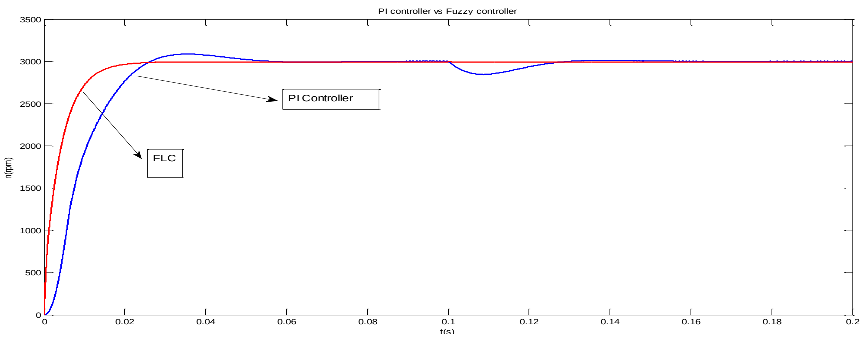

Figure 9. Comparison of speed responses of both PI and FLC

It can be conclude the speed response of the FLC is fast, without overshoot and presents high load robustness at 0.1 s. But the speed response of the conventional PI controller is vulnerable facing the change of the load as is shown at 0.1s. The Table 4 below presents the characteristics of both responses.

Table 4. Response's Characteristics of PI and FLC Controllers

PI controller	Fuzzy controller
RiseTime: 0.0157 s	RiseTime: 0.0095
SettlingTime: 0.1205 s	SettlingTime: 0.0174
SettlingMin: 2.7001e+003	SettlingMin: 2.7003e+003
SettlingMax: 3.0854e+003	SettlingMax: 2.9947e+003
Overshoot: 2.8470	Overshoot: 0
Undershoot: 0	Undershoot: 0
Peak: 3.0854e+003 s	Peak: 2.9947e+003
PeakTime: 0.0359 s	PeakTime: 0.1001

The Figure 10 shows the robustness of the FLC vs the PI controller as is shown at the begging where the FLC is very faster than the PI controller and also at 0.1 s where the FLC has follows rapidly the load change, while the PI controller was late.

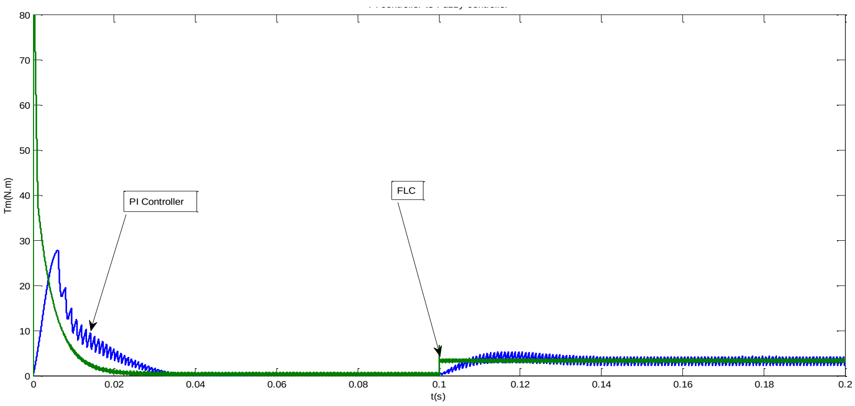

Figure 10. Comparison of electromagnetic torque of BLDC for both PI and FLC

6. CONCLUSION

A fuzzy logic controller (FLC) has been used to improve BLDC's response. Simulation and results analysis of the performance of a fuzzy controller using mamdani method and centroid defuzzification are presented. Simulation results showed that FLC reduces overshoot and settling time and this controller also provides more efficient closed loop response for position control of BLDC motor than the conventional PI controller. This robustness is clearly shown via the electromagnetic torque at 0.1s where it follows perfectly the load change. FLC will dominate the scooter's technology due its better performances and especially when changing suddenly the speed.

REFERENCES

[1] Air quality in Europe – 2011 report, EEA technical–report no. 12/2011. *European Environmental Agency.*

[2] Dekker, P. W. K., "Electrification of Road Transport–An Analysis of the Economic Performance of Electric Two Wheelers," *Utrecht University*, 2013.

[3] *http://www.oxforddictionaries.com/definition/english/scooter*, June, 2014.

[4] Directive 2002/24/EC of the European Parliament and of the Council of 18 March 2002 Relating to the Type-approval of Two or Three-wheel Motor Vehicles.

[5] Lia, F. *et al.*, "Promotion of E-bikes for Delivery of Goods in European Urban Areas: an Italian Case Study," 2014.

[6] Gruber, J., Kihm, A. & Lenz, B., "A New Vehicle for Urban Freight? An Ex-ante Evaluation of Electric Cargo Bikes in Courier Services," Research in Transportation Business & … 11, pp.53–62, 2014

[7] Jorna, R. & Mallens, M., "PRO-E-BIKE Promoting electric bikes and scooters for delivery of goods and passenger transport in urban areas," 2013.

[8] Browne, M., Allen, J. & Leonardi, J., "Evaluating the use of an urban consolidation centre and electric vehicles in central London," *IATSSR*, 35(1), pp. 1–6, 2011.

[9] Macário, R., Rodrigues, M. & Gama, A., "Deliverable 2 Business Concepts and Models for urban logistics," Lisboa, 2011.

[10] Atef Saleh Othman Al-Mashakbeh, "Proportional Integral and Derivative Control of Brushless DC Motor," *European Journal of Scientific Research ISSN 1450-216X*, vol. 35 No. 2, 2009, pp. 198-203.

[11] N. Hemati, J. S. Thorp, and M. C. Leu, "Robust Nonlinear Control of Brushless Dc Motors for Directdrive Robotic Applications," *IEEE Trans. Ind. Electron*, vol. 37, pp. 460–468, Dec. 1990.

[12] P. M. Pelczewski and U. H. Kunz, 'The Optimal Control of a Constrained Drive System with Brushless Dc Motor,' IEEE Trans. Ind. Electron, vol. 37, pp. 342– 348, Oct. 1990.

[13] *http//:www.expressoscooter.com, Retrieved 3 November 2017*

[14] P. C Krause O. Wasynozuk, S. D. Sudhoff, "Analysis of Electric Machinery and Drive Systems," *IEEE Press, Second Edition*, 2002.

[15] Anjali. A. R, "Control of Three Phase BLDC Motor Using Fuzzy Logic Controller," *International Journal of Engineering Research & Technology (IJERT)*, vol. 2 Issue 7, July 2013.